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STATISTICAL ANALYSIS OF U.S. NAVY MAJOR AIRCRAFT ACCIDENT RATES, PILOT AND AIRCRAFT TIME-DEPENDENT VARIABLES

by

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March 1977

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Statistical Analysis of U.S. Navy Major Aircraft Accident Rates, Pilot and Aircraft Time-Dependent Variables

by

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ABSTRACT

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I. INTRODUCTION

The increased dollar cost of procuring both aircraft and pilots places a great emphasis for determining a viable method to reduce Navy and Marine aircraft accidents. Many research efforts have been undertaken to determine the accident causal factors. Once these factors are identified, they might be used to reduce the future mishaps.

Aircraft accidents have been broadly categorized in terms of causal factors determined by the aircraft investigation teams. These categories are described in the Manual of code classification for Navy aircraft accident, incident, and ground accident reporting (1972). An accident is designated as a major accident if: 1) loss of life is involved; 2) complete loss of an aircraft in involved; or 3) substantial damage occurs to any aircraft involved where substantial damage is defined in Appendix A of OPNAVINST 3750-6 (series).

In the previous studies, the most common causal factor identified was pilot error. Brictson (1969) studied a four-year span of aircraft carrier landing accidents involving attack and fighter aircraft. Approximately seventy-eight percent of the accidents studied had pilot error as the primary causal factor. The data of all Navy/Marine major aircraft accidents for FY 1968-1974 shows that about 19% of the accidents had pilot error as the primary causal factor (40% primary and secondary), 22% were attributed to

to other personnel, 26% was attributed to material failure or malfunction (normal wear and tear), approximately 20% were undetermined, and the remainder was attributed to other causal factors.

Some analysts feel that if pilot error is a primary cause of accidents, then the more proficient pilot should make fewer errors. But it may be quite difficult to determine a single factor which makes a pilot proficient. Zeller (1961) hypothesized that the amount of flight time logged by a pilot during a given period was positively correlated with optimal proficiency. He intimated that were a pilot to fly the proper amount, he would attain a safe, proficient ability as a pilot. The procedure of how to determine the proper amount of flight time necessary to attain proficiency and how the number of hours needed would interact with fatigue and complacency were not fully explored.

Borowski (1976) has analyzed the effects of flying time on pilot factor accident rates, considering the flying records of the population of pilots who have not been involved in accidents as well as those who have had accidents. According to the author: 1) there exist no significant relationships between pilot factor accidents and total pilot experience in all models; 2) there exists a significant relationship between pilot factor accidents and flight time in past 90 days. Moreover, the rates tend to increase with increasing time in 90 days to approximately 50 hours and decrease thereon; 3) the multivariate analysis does not

indicate that experienced aviators operate significantly more safely during time of reduced flight activity than inexperienced aviators. A critical factor in aviation safety appears to be time in past 90 days - independent of total pilot experience.

The study made by Robino (1974) showed that there is a cyclic effect in the monthly accident rates with the month of March significantly higher. The work done by Zeller and Marsh (1973) on seasonal trend variations in USAF aircraft accidents shows that when all the aircrafts were considered, the curve approximated a sine wave with peaks in January and July and low points in March and October. But the study done by Poock (1976) does not support the March, January or July phenomena. According to the author the average monthly accident rates are uniformly distributed over time.

The author of this study agrees that if a statistical analysis of aircraft accident rates can provide information on accident related variables, be they pilot oriented, aircraft oriented or related to some other source, which vary either directly or inversely with aircraft accident rates, then preventive actions should be taken to suppress the enormous costs in dollars and human life associated with aircraft accidents.

II. NATURE OF THE PROBLEM

Monthly accident rates exhibit a marked variability when each calender month is compared to other months. The belief that some monthly rates are consistently higher than others have been noted frequently in studies. This phenomena has been noted in studies of U.S. Air Force accident rates by Zeller and March (1973) and by Robino (1972) in a study of Navy aircraft accident rates. Recent work by Poock (1976) at the U.S. Naval Postgraduate School displays no statistical basis for any month being consistently high and the author attributes the fluctuations to random effects of the underlying causal factors.

The accident rate is defined as the total number of accidents in a given month times ten-thousand hours divided by the total number of flight hours flown that month.

The previous studies by Stucki and Maxwell (1975), Johnson (1976) and Bucher (1976) at the Naval Postgraduate School, have explored accident rates dependence on time related variables of those pilots and aircrafts which had the accidents.

The effort of this study is to: 1) analyze the variability of monthly aircraft accidents, for any trend or cyclic effect and; 2) analyze the effects, of time related pilot and aircraft variables on the accident rates, considering

the pilots and aircrafts which have not been involved in accidents as well as those who have had accidents.

III. ANALYTICAL PROCEDURES

This chapter contains the data selection procedure, the methodology for data preparation, a description of the analysis procedure and a summary of decision criterion employed in testing the hypothesis that accident rates are randomly distributed over time, and that pilot and aircraft variables have no effect on accident rates.

A. DATA SOURCE

All Navy and Marine aircraft accidents and incidents are reported in detail to the Naval Safety Center (NSC) Norfolk, Va. for inclusion in their master data bank. The reporting criterion is detailed in Navy Aircraft Accidents, Incidents and Ground Reporting Procedures (OPNAVINST 3760.6 Series). As Naval Safety Center maintains the master data bank, they are, therefore the source of data used in this report. The data of the pilots who did not have the accidents was obtained from the Individual Flight Activity Reporting System (IFARS) data bank through NSC. The data of the aircrafts who did not have the accidents was obtained from Aircraft Management Information Systems Branch CNO (OP-511).

B. DATA SELECTION

The NSC data bank provides a ready source of data. The 2110 computer data cards previously obtained from NSC for

previous studies were also used in this study.

The initial step in the conduct of current accident rate analysis was to select appropriate variable measures or data points. A data point for an accident was considered to be any suitable variable measure associated with the accident and a data set consisted of data points for a specific accident.

Selection of appropriate data points required that each point be time dependent. Data point time dependency and subsequent selection was based on the variable descriptions contained in the manual of code classification for Navy Aircraft accident, Incident and Ground Accident Reporting (Code Manual) promulgated by NSC. Table 1 lists the data initially requested from and provided by Naval Safety Center.

From the available data set, seven basic variables were selected in cooperation with Naval Safety Center personnel for inclusion in this study. The variables are listed in Table 2. To analyze the effects of all the seven variables, on aircraft accident rates considering the population of pilots and aircrafts who had not been involved in accidents as well as those who had accidents, the data for the pilots who did not have an accident was requested from NSC. The data set provided was for CY 1971 to 1974, inclusive. The data set available on accidents was for FY 1968 to 1974. The time span, therefore, was selected for CY 1971 - 1973.

TABLE 1

DATA SET REQUESTED FROM NAVAL SAFETY CENTER

Data concerning the pilot:

1. Age
2. Injuries
3. Number of previous service tours
4. Total flying time in aircraft model in which accident occurred
5. Total flight hours in previous ninety days
6. Total nighttime flight hours in previous ninety days
7. Total daylight carrier landings in previous thirty days
8. Total night carrier landings in previous thirty days
9. Number of years as designated Naval Aviator

Date concerning aircraft:

1. Model
2. Damage
3. Number of tours between major aircraft rework
4. Type of last major inspection
5. Hours since last inspection
6. Identification of the system or component failure

Date concerning the flight:

1. Major command
2. Reporting custodian
3. Ship's hull number (if applicable)
4. Marine Air Wing (if applicable)
5. Location
6. Flight Purpose Code
7. Type of operation code
8. Phase of operation in which the accident occurred

Data concerning the accident:

1. Accident identification number including calendar date
2. Other aircraft damaged
3. Other personnel injured
4. Contributing causal factors
5. Special data not otherwise listed
6. Weather
7. Accident rate for the month in which the accident occurred

TABLE 2

1. Accident rate by month (RATE)

2. Pilot age (AGE)

3. Number of years designated Naval Aviator (DNA)

4. Total flight time in accident involved aircraft model (T TIME)

5. Total flight time during ninety days preceding accident (TOT 90)

6. Number of aircraft tours (ACTRS)

7. Aircraft flight hours since last major or calender inspection (ACHRS)

C. VARIABLE SELECTION

The author of this study intended to include all the variables listed in Table 2. But the data of nonaccident pilots consisted of pilot age, years as designated Naval aviator, total pilot and co-pilot hours all models cumulative, total first pilot hours for the model for one year and total pilot and co-pilot hours in last 90 days. The data for the pilot hours in last 90 days was not updated for about 60% of the pilots. Total pilot hours all models and total pilot hours for one year were not compatible with the accident data. The variables included in this study are listed in Table 3.

TABLE 3

DATA SET INCLUDED IN CURRENT STUDY

1. Accident rate by month (RATE)
2. Pilot age (AGE)
3. Number of years designated Naval Aviator (DNA)
4. Number of aircraft tours (ACTRS)
5. Aircraft flight hours since last major or calender inspection (ACHRS)

Pilot age and years designated Naval Aviator were included as they are the variables that are historically used as indicator of maturity and perhaps proficiency. If, as the author believes, the hypothesis that the older pilots tend to be safer pilots through a finer sense of judgement of risks involved is a valid hypothesis, then the accidents per hundred pilots will decrease with increase in age or DNA and will not be uniformly distributed.

Aircraft tours is included as a measure of the general condition of the aircraft and an indication of aircraft age. Each aircraft in the Navy's inventory undergoes a periodic Aircraft Rework (PAR) for analysis, repair and conversion at intervals unique to the model aircraft after a specific number of flight hours.

Aircraft hours is included as a measure of aircraft condition and usage since last major inspection. Each aircraft after undergoing a major inspection is considered to be new. These two variables, therefore, serve to monitor the reliability anomalies such as "new better than used" or "used better than new".

D. DATA PREPARATION

The accident rate is defined as the total number of accidents in a given month times ten thousand hours divided by the total number of flight hours flown that month. The accident rates were evaluated for each type of aircraft. In case there were a few accidents in some types of aircrafts because of small inventory or any other reason, the data was

grouped under such categories as propellers, attack or helos. After grouping the data where necessary, the following types of aircrafts or group of aircrafts were considered:

A-4
A-6
A-7
Fighters
F-4
Propellers
Helicopters

The accident rates are listed in Appendix B.

In order to analyze the effects of age, DNA, ACTRS and ACHRS on accidents, the flying records of the population of pilots who had not been involved in accidents as well as those who had accidents were considered. The Individual Flight Activity Reporting System (IFARS) data bank was used to obtain the required information. As the data of all the pilots for three years is of a very large amount (about 90,000 data points) the aircrafts considered for analysis were A-4, A-7 and F-4 as the respective representatives of attack and fighter communities. Using the subroutine HIST G available at the NPG School computer facility, histograms of age of pilots and years of DNA were plotted. This gave the number of pilots in each category of age and DNA. The interval used was of one year both for age and DNA. Similarly the histograms were plotted for age and years of DNA for those pilots who had the accidents for the same time period and for the same categories. This gave the number of pilots in each age category and years of DNA who had accidents.

The data of aircrafts not involved in major accidents was obtained from Aircraft Information System Branch (AISB-OP511). The data provided was on microfilm. The data requested and provided was for FY 1972 - 1976. The data for FY 1974 was confidential, therefore, the data for FY 1972 and 1973 was included in the study. Aircraft tours and hours since last major inspection were read and recorded from the microfilm with the help of microfilm reader. This was a very labourious and time consuming task. The analysis done, therefore, was for F-4, the representative of the fighter community. The following data were obtained:

(1) The number of aircrafts in each interval of aircraft tour in the two-year period FY 1972 - 73. The categories for aircraft tour were (0, 1}, (1, 2}, ... (7, 8}. (The notation (a, b} denotes "greater than a and less than or equal to b".)

(2) The number of aircrafts in each interval of aircraft hours since last major inspection. The categories were (0, 40}, (40, 80}, ... (1240, 1280}.

The data on accidents was on computer cards. Using the subroutine HIST G. the histograms for ACTRS and ACHRS were plotted using the same categories as above. The information obtained was the number of aircrafts in each category of ACTRS and ACHRS who had accidents.

E. THE ANALYSIS TECHNIQUE

Each variable listed in Table 3 was analyzed independently for each type of aircraft or group of aircrafts. The analysis techniques employed are described in the following

paragraphs.

1. Accident Rate by Month (RATE)

The study made by Robino (1976) showed that there is a cyclic effect in the monthly accident rates and work by Zeller and Marsh (1973) pointed out that there is a seasonal trend in the accident rates. To analyze whether the accident rates by month are random attributable to chance variation only, or if there is a cyclic pattern or if there is a seasonal trend, the technique of a Runs test was employed to the runs above and below the median. The Runs test is described in Appendix A. The confidence used to test the null hypothesis was 95% for all the tests.

2. Pilot and Aircraft Variables

The studies by Stucki and Maxwell (1975), Johnson (1976) and Bucher (1976) employed multiple regression to find pilot and aircraft variables related to accident rate. Age was the most significant single variable in the overall equation arrived at in the study by Stucki and Maxwell and DNA, T TIME, ACTRS and ACHRS appeared in the equations arrived at in the study by Johnson and Bucher. This study did not use multiple regression but rather analyzed each variable independently. The null hypothesis used was that the number of accidents per hundred pilots is equal in each category of pilot or aircraft variable. Accidents per hundred pilots is defined as the number of accidents in a particular age/DNA category times one hundred divided by the population of pilots in that category.

The X^2, one sample test, was used to test the null hypothesis that the accidents per hundred pilots are equal in each category. The X^2 test for K independent samples was used to test that the proportion of accidents per hundred pilots is the same in all age or DNA categories for all the three aircrafts considered. The graphs of the accidents per hundred pilots are given in Appendix C. It was observed that the accidents per hundred pilots were generally higher for the age group (24-29) than the age group (30-40) and in case of DNA higher for DNA (0-3) as compared with DNA (4-18). To test whether this is significant the Mann-Whitney U test[1] was used. The samples of the two intervals were considered to be independent because the accidents in one category are independent of the accidents in other categories. The critical values of the statistic U are tabulated in most of the non-parametric statistics books. The Mann-Whitney U test is one of the most powerful of the non-parametric tests, and it is a most useful alternative to the parametric t test.

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[1] Siegel, Non-Parametric Statistics for the Behavioral Sciences, p. 116

IV. RESULTS

The results of the analysis of Accident Rates by Month, Pilot and Aircraft variables listed in Table 3 are contained in this chapter.

A. ACCIDENT RATE BY MONTH (RATE)

The accident rates for each type of aircraft or group of aircrafts are listed in Appendix B. The Runs test based on data above and below the median was used to test the null hypothesis. The hypothesis tested is:

Ho: The accident rate by month are randomly distributed

H1: There is a trend or cyclic effect in the monthly accident rates.

The results by aircraft type or aircraft community are given below.

1. A-4 Aircraft

This category contains all accident involved A-4 and TA-4 aircraft in the three-year period FY 1972 - 1974 and provides a sample size of thirty-one cases. The run test gave the following results:

Sample size	$N = 31$
Median	$= 1.18$
The number of values above the median	$n_1 = 15$
The number of values below the median	$n_2 = 15$
The observed number of runs	$R = 14$

The values of n_1 and n_2 are greater than ten, therefore, the sampling distribution of R is approximated with a normal distribution. The calculated $Z = -0.74$ (Z is the standardized

value of normal random variable.) At 95% confidence level the hypothesis Ho is not rejected. That is, the accident rates are randomly distributed and there is no trend or cyclic pattern.

2. A-6 Aircraft

This category was restricted to a sample size of twenty due to relatively few accidents and smaller community. In order to achieve the largest sample size possible the author included EA-6 aircraft with the A-6 and KA-6 models. Applying the run test to the accident rates listed in Appendix B, the following results were obtained:

Sample size	$N = 20$
Median	$= 1.45$
The number of values above the median	$n_1 = 10$
The number of values below the median	$n_2 = 10$
The observed number of runs	$R = 14$

The computed $Z = 0$. Therefore at 95% confidence level the hypothesis Ho is not rejected.

3. A-7 Aircraft

This category provided a sample size of thirty-two cases based on all A-7 aircraft models involved in accidents during the study period. The reslts of the run test are as follows:

Sample size	$N = 32$
Median	$= 1.76$
The number of values above the median	$n_1 = 16$
The number of values below the median	$n_2 = 16$
The observed number of runs	$R = 11$

The computed $Z = -2.15$. Therefore at 95% confidence level the hypothesis Ho is rejected in favor of H1. $Z < -Z_{0.05}$,

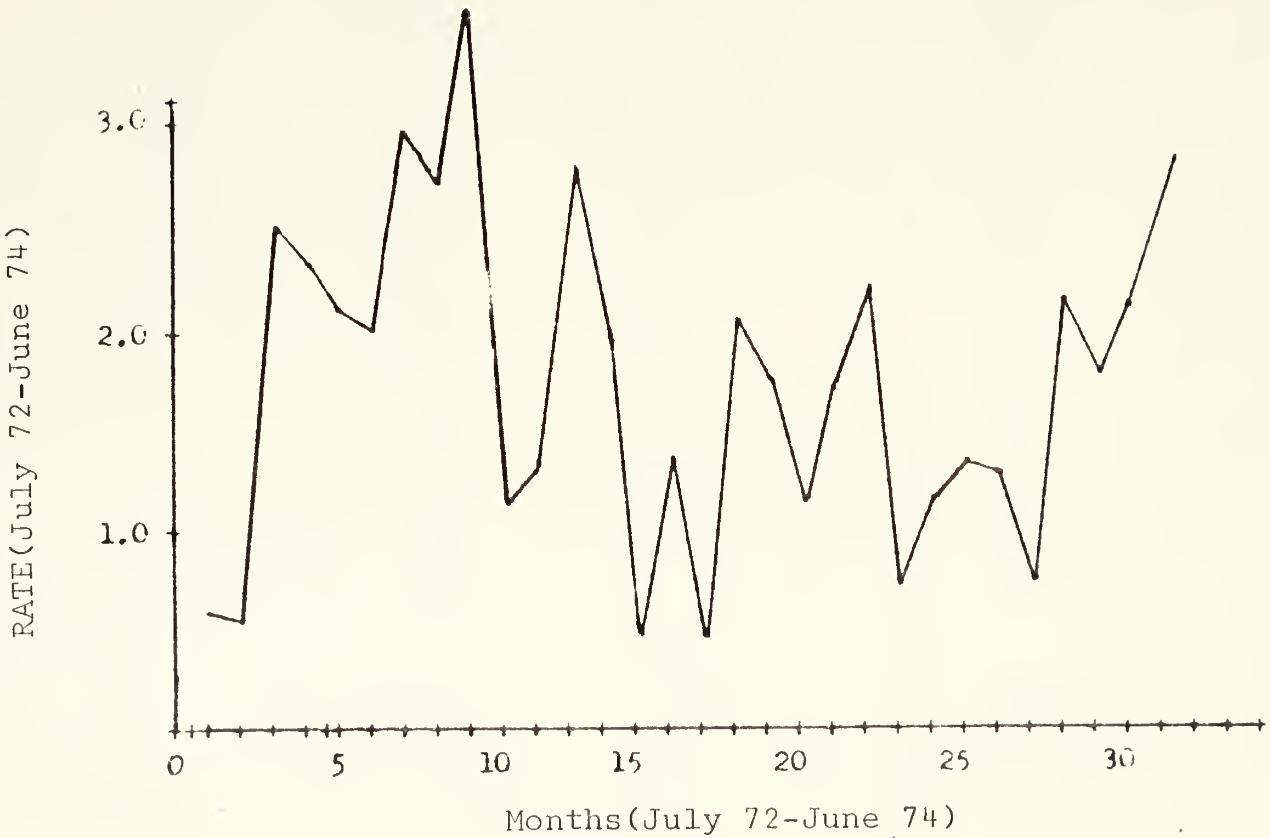

Figure 1: A-7 Aircraft Accident Rates by Month(July 72-June74)
(Linear Interpolation Between Data Points)

therefore there is a trend in the monthly accident rates and the graphic plot (Figure 1) shows a decreasing trend.

4. Fighter Composite

This category includes F-4 and F-8 aircraft. The data base did not provide enough data to conduct independent analysis of F-8s by themselves which led to the composite category. The composite analysis yielded a sample size of thirty-six cases primarily on the strength of F-4 community. The results of the analysis are:

Sample size	$N = 36$
Median	$= 1.685$
The number of values above the median	$n_1 = 18$
The number of values below the median	$n_2 = 18$
The observed number of runs	$R = 16$

The calculated $Z = -1.014$. Therefore at 95% confidence level, the hypothesis Ho is not rejected.

5. F-4 Aircraft

The category of F-4 aircraft consisted of a sample size of thirty-six data points. The run test yielded the following results:

Sample size	$N = 36$
Median	$= 1.65$
The number of values above the median	$n_1 = 18$
The number of values below the median	$n_2 = 18$
The number of observed runs	$R = 18$

The computed $Z = -0.339$. Therefore at 95% confidence the hypothesis Ho is not rejected.

6. Propeller Aircraft

The aircraft considered in the propeller aircraft category consisted of E-1, E-2, C-1, C-2, S-2, P-3, C-117, C-118 and C-130. Due to the relatively small size of each

individual community and the infrequency of accidents it was necessary to combine all aircraft into one category. The result of aggregate is a sample size of 26 cases. Applying the runs test to the runs above and below the median the following results were obtained:

Sample size	$N = 26$
Median	$= 0.355$
The number of values above the median	$n_1 = 13$
The number of values below the median	$n_2 = 13$
The observed number of runs	$R = 13$

The calculated $Z = -0.37$. At 95% confidence level the hypothesis Ho is not rejected.

7. Helicopters

The category of helicopters consists of aggregate of H-1, H-2, H-3, H-46 and H-53. The aggregate yielded a sample size of thirty-three cases. The run test gave the following results:

Sample size	$N = 33$
Median	$= 0.9$
The number of values above the median	$n_1 = 16$
The number of values below the median	$n_2 = 16$
The number of observed runs	$R = 18$

The calculated $Z = -0.35$. Therefore at 95% confidence level the hypothesis Ho will not be rejected.

B. PILOT AGE AND DNA

In order to analyze the effect of pilot age and years of DNA on aircraft accident the flying records of the population of pilots who have not been involved in accidents as well as those who have had accidents were considered. The analysis was made for the aircrafts of the types F-4, A-4 and A-7,

the representatives of fighter and attack communities. All the pilots who had been flying the above types of aircraft during the analysis period CY 1971 - 1973 were considered. The three year's data will also imply that if a pilot had been flying the same type of aircraft in CY 1971 - 73 he will constitute three data points because in each year he will be in the next age and DNA category. The X^2 one-sample test was used to test the null hypothesis. The null hypothesis used was that the number of accidents per hundred pilots in each category of pilot variable were equal. In other words there is no effect of pilot age or DNA on aircraft accidents. The data and the results of the test by aircraft type are given below.

1. A-4 Aircraft

In this category all the pilots of A-4 and TA-4 were included.

(1) Age Analysis: The Number of Accidents vs the Population of pilots in each Age Category

TABLE 4

ACCIDENTS AND POPULATION OF PILOTS
IN EACH AGE CATEGORY (A-4)

Age	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
[23-24)	5	691	0.72
[24-25)	14	553	2.53
[25-26)	7	808	0.86
[26-27)	22	768	2.86
[27-28)	16	639	2.50
[28-29)	8	539	1.48
[29-30)	29	492	5.89
[30=31)	10	365	2.73
[31-32)	12	252	4.76
[32-33)	5	171	3.31
[33-34)	4	151	2.64
[34-35)	2	143	1.39
[35-36)	3	195	1.53
[36-37)	4	214	1.86
[37-38)	2	265	0.75

The hypothesis tested is Ho: P23 = P24 --------------- = P37

The calculated $\chi^2 = 6.30$ (Table 4, each two adjacent categories were combined from the top of the table down and the last three were combined). The critical $\chi^2_{0.05(6)} = 12.59$. Therefore at the 95% confidence level the hypothesis Ho is not rejected. Moreover, the Mann-Whitney U test was applied to test the hypothesis that the average accidents per hundred pilots for the age groups (23-29) and (30-37) were equal. The value of U (the statistics used in this test) = 25. For $n_1 = 8$, $n_2 = 8$ the $P(U \leq 25) = 0.347$. Therefore at 95% confidence level the Ho is not rejected.

(2) DNA Analysis.

TABLE 5

ACCIDENTS AND POPULATION OF PILOTS
IN EACH DNA CATEGORY (A-4)

DNA	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
(0-1}	46	2036	2.25
(1-2}	14	714	1.96
(2-3}	9	641	1.40
(3-4}	11	541	2.03
(4-5}	13	509	2.55
(5-6}	4	366	1.09
(6-7}	2	236	0.84
(7-8}	6	173	3.46
(8-9}	6	149	4.02
{10-14}	32	929	3.44
{15-18}	2	743	0.26

The hypothesis tested is Ho: $P_1 = P_2$ ----------------- $= P_{18}$

The computed $\chi^2 = 3.08$ (Table 5, each two adjacent categories were combined as well as the last three). The $\chi^2_{0.05(4)} = 9.49$. Therefore at 95% confidence level Ho is not rejected. Moreover, the Mann-Whitney U test was applied to test the hypothesis that the means of the accidents per hundred pilots for the DNA groups (0-3) and (4-18) were equal. The results of the test are:

$$n_1 = 3$$
$$n_2 = 8$$
$$u = 10$$

The $P(U \leq 10) = 0.387$. The $\alpha = 0.05$, therefore Ho is not rejected.

2. <u>A-7 Aircraft</u>

In this category all the pilots of A-7 type aircraft were considered.

(1) Age Analysis

TABLE 6

ACCIDENTS AND POPULATION OF PILOTS
IN EACH AGE CATEGORY (A-7)

Age	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
{24-25)	7	283	2.47
{25-26)	21	202	10.39
{26-27)	17	272	6.25
{27-28)	12	301	3.98
{28-29)	3	236	1.28
{29-30)	27	235	11.48
{30-31)	4	172	2.32
{31-32)	13	148	8.78
{32-33)	3	95	3.15
{33-34)	1	85	1.17
{34-35)	4	81	4.93
{35-36)	0	105	0.00
{36-37)	1	106	0.94
{37-38)	4	125	3.20
{38-39)	2	104	1.92
{39-40)	2	99	2.02
{40-48)	3	205	1.46

The hypothesis tested is Ho: $P_{24} = P_{25}$ -------------- $= P_{40}$

The hypothesis Ho is rejected at the 95% confidence level (from Table 6 $\chi^2 = 16.44$, $\chi^2_{0.05(7)} = 14.7$, each two adjacent categories were combined as well as the last three).

Moreover:

(a) For age 24-29, $\chi^2 = 14.77$, $\chi^2_{0.05(5)} = 11.07$, therefore there is significant difference in each category of this interval.

(b) For age 30-40, $\chi^2 = 7.467$, $\chi^2_{0.05(6)} = 9.49$, therefore there is no significant difference in accidents per hundred pilots for this interval.

(c) The mean accidents per 100 pilots for age 24-29 is greater than the mean accidents per 100 pilots for age 30-40 at 95% significance level (Mann-Whitney U test statistics $U = 15$, $n_1 = 6$, $n_2 = 11$ and critical $U_{0.05,\,6,\,11} = 16$).

(2) DNA Analysis

TABLE 7

ACCIDENTS AND POPULATION OF PILOTS
IN EACH DNA CATEGORY (A-7)

DNA	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
{0-1}	27	411	6.59
(1-2}	20	290	6.89
(2-3}	22	345	6.37
(3-4}	6	280	2.14
(4-5}	5	207	2.41
(5-6}	4	154	2.59
(6-7}	4	126	3.17
(7-8}	2	74	2.70
(8-9}	0	78	0.00
{10-14}	28	520	5.38
{15-18}	6	327	1.83

The hypothesis tested is Ho: $P_1 = P_2$ --------------- $= P_{18}$

The calculated $\chi^2 = 7.68$ (Table 7, each two adjacent categories were combined as well as the last three). The $\chi^2_{0.05(4)} = 9.49$. Therefore Ho is not rejected, but when the means of the accidents per hundred pilots for the DNA values (0-3) and (4-18) were compared, the mean for the DNA one to three was significantly higher than the mean for the DNA four to eighteen ($n_1 = 3$, $n_2 = 8$, $U = 0$, the $P(U \leq 0) = 0.006$).

3. <u>F-4 Aircraft</u>

In this category all the pilots of F-4 aircraft were considered.

(1) Age Analysis

TABLE 8

ACCIDENTS AND POPULATION OF PILOTS
IN EACH AGE CATEGORY (F-4)

DNA	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
{24-25)	17	127	13.3
{25-26)	18	145	12.4
{26-27)	24	181	13.2
{27-28)	12	202	5.9
{28-29)	14	205	6.8
{29-30)	24	202	11.8
{30-31)	5	122	4.09
{31-32)	3	89	3.33
{32-33)	4	75	5.33
{33-34)	3	72	4.16
{34-35)	0	51	0.0
{35-36)	1	58	1.72
{36-37)	1	86	1.16
{37-38)	2	85	2.35
{38-39)	2	89	5.61
{39-40)	1	79	1.26
{40-48)	3	137	2.18

The hypothesis tested is Ho: $P_{24} = P_{25}$ -------------- $= P_{40}$

The hypothesis Ho is rejected at the 95% confidence level (from Table 8 $\chi^2 = 57.4$, $\chi^2_{0.05(16)} = 26.30$).

(a) For age 24 to 29, the $\chi^2 = 5.25$ and $\chi^2_{0.05(5)} = 11.07$, therefore there is no significant difference in each category of this interval.

(b) For age 30 to 40 the $\chi^2 = 8.615$ (the two adjacent categories were combined as well as the last three). The $\chi^2_{0.05(6)} = 9.49$, therefore there is no significant difference in accidents per hundred pilots for this interval.

(c) The mean accidents per 100 pilots for age 24-29 is greater than the mean accidents per 100 pilots for age 30 to 40 at 95% significance level (Mann-Whitney U test statistics $U = 0$, $n_1 = 6$, $n_2 = 11$ and $U_{0.05(6,\ 11)} = 16$).

(2) DNA Analysis

TABLE 9

ACCIDENTS AND POPULATION OF PILOTS
IN EACH DNA CATEGORY (F-4)

DNA	Number of Accidents	Population of Pilots	Accidents per 100 Pilots P_x
{0-1}	39	319	12.22
(1-2}	30	189	15.87
(2-3}	22	243	9.05
(3-4}	4	201	1.99
(4-5}	9	174	5.17
(5-6}	8	111	7.2
(6-7}	2	79	2.53
(7-8}	1	61	1.63
(8-9}	3	56	5.35
{10-14}	20	320	6.25
{15-18}	5	267	1.87

The hypothesis tested is Ho: $P_1 = P_2$ --------------- $= P_{18}$

The hypothesis Ho is rejected at the 95% confidence level

(from Table 9 $\chi^2 = 33.66$, and $\chi^2_{0.05(10)} = 18.307$).

(a) For DNA 3 to 18, the $\chi^2 = 12.64$ and $\chi^2_{0.05(8)} = 15.5$, there is no significant difference in each category of this interval.

(b) The mean for the DNA zero to three was significantly higher than the mean for the DNA four to eighteen ($n_1 = 3$, $n_2 = 8$, $U = 0$, the $P(U \leq 0) = 0.006$).

4. <u>A-4, A-7 and F-4 Aircraft</u>

The data of all the three aircrafts was considered to test the hypothesis that the accidents per hundred pilots had the same profile or in other words they were from the populations with the same distribution. The results of the χ^2 test for K independent samples is given below for both the variable age and variable DNA.

(1) Age Analysis

TABLE 10

ACCIDENTS PER 100 PILOTS

Expected Value in ( )

Pilot Age	A-4	A-7	F-4	Total
{23-24}	(7.6) 3.39	(14.07) 12.86	(20.26) 25.7	41.95
{25-26}	(6.29) 5.36	(11.6) 10.23	(16.77) 19.1	34.72
{27-28}	(7.02) 7.37	(12.99) 12.76	(18.7) 18.6	38.73
{29-30}	(4.69) 7.49	(8.69) 11.10	(12.51) 7.42	25.91
{31-34}	(5.31) 8.87	(9.84) 9.25	(14.17) 11.2	29.33
{35-40}	(4.56) 3.05	(8.43) 9.54	(12.15) 12.56	25.15
Total	35.53	65.74	94.67	195.9

The hypothesis tested is Ho: The proportion of accidents per hundred pilots is the same in all age categories for the three aircrafts. In other words the profile of accidents per hundred pilots is the same for all the three aircrafts.

The calculated χ^2 = 12.64 (Table 10). The $\chi^2_{0.05(10)}$ = 18.31. Therefore the hypothesis Ho is not rejected at 95% confidence level

(2) DNA Factor Analysis

TABLE 11

ACCIDENTS PER 100 PILOTS

Expected Value ( )

		A-4	A-7	F-4	Total
Pilot DNA	{1-2}	(8.04) 4.21	(13.82) 13.45	(23.87) 28.09	45.75
	{3-6}	(7.73) 7.07	(13.29) 13.51	(22.95) 23.41	43.99
	{7-18}	(7.5) 12.02	(12.9) 13.08	(22.28) 17.63	42.7
	Total	23.3	40.04	69.13	

The hypothesis tested is Ho: The proportion of accidents per hundred pilots is the same in all DNA categories for the three aircrafts.

The calculated $\chi^2 = 6.72$ (Table 11). The $\chi^2_{0.05(4)} = 9.49$. Therefore the hypothesis Ho is not rejected at 95% confidence level.

C. ACTRS AND ACHRS

In order to analyze the effect of aircraft tours (ACTRS) and aircraft hours since last major inspection (ACHRS) on aircraft accidents, the maintenance records of the population of aircrafts who have not been involved in accidents as well as those who had accidents were considered. The analysis was made for all models of F-4 aircraft. The data considered was for FY 1972 - 1973. During that period it was possible that one aircraft might have undergone more than one major inspection thus constituting more than one data point. The categories for ACHRS were (0, 40} , (40, 80} ... (1240 - 1280}. If an aircraft have flown more than forty hours during the analysis period it will constitute more than one data point. The χ^2 one-sample test was used to test the hypothesis that the accidents per hundred aircrafts in each category were uniformly distributed. The Mann-Whitney U test was used to see if there is any significant difference in the accidents per hundred aircrafts for different intervals of aircraft variables. The data and the results of the test for F-4 aircraft are given below.

(1) ACTRS Analysis

TABLE 12

ACCIDENTS AND POPULATION OF AIRCRAFTS
IN EACH ACTRS CATEGORY

ACTRS	Number of Accidents	Population of Aircrafts	Accidents per 100 Pilots P_x
{0-1}	17	166	10.24
(1-2}	27	313	8.62
(2-3}	19	213	8.92
(3-4}	8	110	7.27
(4-5}	12	108	11.11
(5-6}	14	83	16.85

The hypothesis tested is Ho: $P_1 = P_2$ --------------- $= P_6$

The calculated $\chi^2 = 5.45$ (Table 12). The $\chi^2_{0.05(5)} = 11.07$. Therefore Ho is not rejected at 95% significance level. There is also no significant differences ($\alpha = 0.05$) in the means of accidents per hundred aircrafts for ACTRS interval (0-4) and (5-6) ($n_1 = 2$, $n_2 = 4$, $U = o$, $P(U \leq 0) = 0.067$).

(2) ACHRS Analysis.

TABLE 13

ACCIDENTS AND POPULATION OF AIRCRAFTS
IN EACH ACHRS CATEGORY

ACHRS	Number of Accidents	Population of Aircrafts	Accidents per 100 Aircrafts P_x
(0-40]	5	435	1.149
(40-80]	6	440	1.363
(80-120]	5	457	1.094
(120-160]	4	466	0.858
(160-200]	5	476	1.050
(200-240]	3	478	0.627
(240-280]	1	497	0.201
(280-320]	5	515	0.970
(320-360]	4	517	0.773
(360-400]	5	519	0.963
(400-440]	2	506	0.395
(440-480]	6	495	1.212
(480-520]	3	476	0.630
(520-560]	6	440	1.363
(560-600]	3	415	0.728
(600-640]	1	379	0.263
(640-680]	2	354	0.564
(680-720]	6	323	1.857
(720-760]	2	276	0.724
(760-800]	2	234	0.854
(800-840]	6	202	2.970
(840-880]	0	172	0.0
(880-920]	1	146	0.684
(920-960]	2	134	1.492
(960-1000]	0	108	0.0
(1000-1040]	0	86	0.0
(1040-1080]	1	76	1.315
(1080-1120]	0	56	0.0
(1120-1160]	1	46	2.17
(1160-1200]	2	29	6.896
(1200-1240]	1	16	6.25

The hypothesis tested is Ho: $P_{0-40} = P_{40-80} ---- = P_{1200-1240}$.

The calcuated $\chi^2 = 19.99$ (Table 13, the first twenty categories were grouped to form four categories and the last eleven categories were grouped to form two categories). The $\chi^2_{0.05(6)} = 12.59$. Therefore the hypothesis Ho is rejected at 95% significance level. But the accidents per hundred pilots for each category are uniformly distributed over ACHRS (0-1160} ($\chi^2 = 0.792$, the six adjacent categories were combined as well as the last five, $\chi^2_{0.05(4)} = 9.49$). Moreover, the means of accidents per hundred aircrafts for ACHRS (1160-1240 are significantly higher when compared with ACHRS (0-1160} ($n_1 = 2$, $n_2 = 29$, $U = 0$ and $U_{0.05(2, 29)} \leq 4$).

V. DISCUSSION

Reviewing the results it can be seen that the monthly accident rates for attack: A-4, A-6; Fighters: F-4; Propellers and Helicopters appear to be randomly distributed according to chance variation. There is no cyclic effect and no decreasing or increasing trend. The results are summarized in Table 14 and it can be seen that except for A-7 the smallest value is P = 0.1562, which is for fighters. This implies that the hypothesis for randomness cannot be rejected at a significance level of even 0.15. The null hypothesis in case of A-7 aircraft is rejected not in favour of cyclic effect but in favour of decreasing trend. It is therefore concluded that there is no cyclic effect in the monthly accident rates and monthly accident rates for all aircrafts except A-7 are randomly distributed.

The author of this study had also analyzed the pilot and aircraft variables listed in Table 2 for accident data only. The distribution of age was the shape of gamma with peak at year 26, DNA was exponentially distributed, TTIME was uniformly distributed, TOT90 had gamma distribution with peak at 60 hours, ACTRS was gamma distributed with peak at 2, and ACHRS were exponentially distributed. Multiple regression was used to fit the equation but the results are not presented in this study because in the opinion of the author, the results would not be meaningful unless the accident data is studied with the non-accident data.

TABLE 14

SUMMARIZED RESULTS OF RUNS TEST

Aircraft Type	Z Values	Probability of Significance (one tailed)
A-4	-0.74	0.229
A-6	0.0	0.5
A-7	-2.15	0.015
Fighters	-1.014	0.1562
F-4	-0.339	0.3707
Propellers	-0.37	0.3557
Helicopters	-0.35	0.3632

For analyzing the accident and non-accident data, the most important thing was to select the suitable hypothesis. The author had considered treating the accident and non-accident data independently and testing the hypothesis that both the samples came from the same population and therefore had the same distribution. But the non-accident data is the entire population and the accident data is the subset of the entire population. Therefore it was considered to be more suitable to test the hypothesis that the accidents per hundred pilots/ aircraft in each category of pilot/aircraft variable was uniformly distributed over the variable considered. The results of the analysis of pilot's age and DNA for uniformity over all the categories or piecewise uniformity over different intervals are summarized in Table 15. Table 16 contains the

summarized results of the comparison of the mean accidents per hundred pilots of the age interval (24-29) with age interval (30-40) and DNA interval (0-3) with DNA interval (4-18). It can be seen that the results are not exactly similar for all the three aircrafts but for both the aircrafts A-7 and F-4, the accidents per hundred pilots are higher for age interval (24-29) when compared with age interval (30-40) and higher for DNA interval (1-3) when compared with DNA interval (4-18).

The accidents per hundred aircrafts for F-4 are uniformly distributed over ACTRS but not uniformly distributed over ACHRS, but when considering the interval (0-1160) hours, the accidents per hundred aircrafts are uniformly distributed, thus satisfying the reliability anomalies that new is better than used.

TABLE 15

ACCIDENTS PER 100 PILOTS

Aircraft Type	Age			DNA	
	24-40	24-29	30-40	0-18	4-18
A-4	Uniform	Uniform	Uniform	Uniform	Uniform
A-7	Not Uniform	Not Uniform	Uniform	Uniform	Uniform
F-4	Not Uniform	Uniform	Uniform	Not Uniform	Uniform

TABLE 16

COMPARISON OF THE MEAN ACCIDENTS PER 100 PILOTS OF THE AGE INTERVAL (24-29) WITH AGE INTERVAL (30-40) AND DNA INTERVAL (0-3) WITH DNA INTERVAL (4-18)

Aircraft Type	Age	DNA
A-4	Equal	Equal
A-7	Higher	Higher
F-4	Higher	Higher

VI. RECOMMENDATIONS

The current study analyzed pilot age and number of years designated as Naval Aviator (DNA) for the pilots who had accidents as well as those who did not have the accidents. The critical age for A-7 and F-4 pilots seemed to be 29 years. The accidents per hundred pilots were significantly higher for age (24-29) when compared with age (30-40). At age thirty the accidents per hundred pilots drops significantly (see Appendix C). The critical year in DNA for A-7 and F-4 pilots, was three. The accidents per hundred pilots are significantly higher for DNA (0-3) compared with DNA (4-18). In the opinion of the author, these results may be further analyzed in view of the pilots's career planning policy. It is further suggested that other pilot variables such as the total flight time in all models, total flight time in the accident involved aircraft model, total flight time during preceding ninety days, day light carrier landings during the preceding thirty days and night carrier landings during the preceding thirty nights, should be analyzed by the same techniques discussed in this study and critical points in a pilot carrier in terms of flight experience may be assertained

The accidents per hundred aircrafts for F-4 were higher for ACTRS 5 and 6 when compared with ACTRS (0-4) though not significant at five percent level, but accidents per hundred aircrafts for ACHRS are significantly higher for ACHRS more than 1160 when compared with ACHRS (0-1160}. It

is suggested that these results may be further analyzed in view of the maintenance policy of F-4 aircraft and if required, the maintenance policy may be reviewed.

APPENDIX A

RUN TEST

A Runs test can be used to test the randomness, trends, or cyclic pattern in the observed data.

A run is a succession of identical letters (or other kinds of symbols) which is followed and preceded by different letters or no letters at all.

The data to be tested for randomness in this study was numerical data. The letters A and B can be used to denote, respectively, values falling above and below the median of the sample. The resulting series of A's and B's can then be tested for randomness on the basis of total number of runs above and below the median.

Too few runs means a decreasing or increasing trend in the observed data. Too many runs will indicate a cyclic pattern in the observed data.

If n_1 is the number of A's and n_2 is the number of B's, then the observed number of runs R can be compared with the expected range of runs tabulated in most of the non parametric statistics books. If n_1 and n_2 are both ten or more, the sampling distribution of R can be approximated with a normal distribution and the value of the standardized normal random variable Z can be computed from the following formula:

$$Z = \frac{(R-1) - \dfrac{2\, n_1\, n_2}{(n_1 + n_2)}}{\left\{ \dfrac{2\, n_1\, n_2 (2\, n_1\, n_2 - n_1 - n_2)}{(n_1 + n_2)^2\, (n_1 + n_2 - 1)} \right\}^{2}}$$

APPENDIX B

ACCIDENT RATES BY MONTH FOR FY JULY 1972 - JUNE 1974

Month	A-4	A-6	A-7	Fighter Composite	F-4	Propeller	Helicopter
JUL	0.0	1.32	0.60	0.36	1.36	0.36	1.61
AUG	2.94	1.13	0.58	1.38	1.82	0.17	0.94
SEP	1.20	0.0	2.51	1.07	1.24	0.17	1.95
OCT	0.81	3.92	2.35	1.52	1.38	0.0	1.00
NOV	1.97	1.22	2.13	0.72	1.25	0.35	0.61
DEC	0.88	0.0	2.09	1.60	1.25	0.99	2.06
JAN	0.46	1.25	3.00	2.36	1.80	0.58	0.71
FEB	1.10	0.0	2.77	1.14	0.64	0.26	0.66
MAR	0.67	0.0	3.61	1.68	2.13	0.33	0.29
APR	1.87	2.77	1.11	3.73	3.34	0.0	0.87
MAY	1.43	1.63	1.29	1.35	1.53	0.17	0.86
JUN	0.0	0.89	2.83	1.68	2.33	0.17	1.73
JUL	2.22	3.16	1.96	4.15	4.53	0.38	0.57
AUG	1.66	1.92	0.45	4.01	2.91	0.17	0.62
SEP	1.16	0.0	1.38	2.0	1.22	0.0	0.91
OCT	1.15	1.77	0.49	0.83	1.17	0.0	0.98
NOV	3.02	1.80	2.03	1.69	1.76	0.18	0.63
DEC	0.50	2.31	0.0	4.11	3.53	0.63	1.43
JAN	0.47	0.0	1.75	2.16	2.96	0.39	1.64
FEB	1.61	0.0	1.17	1.04	1.47	0.19	0.65
MAR	2.00	1.12	0.0	2.04	2.06	0.35	1.65
APR	0.70	0.0	1.79	3.22	3.08	0.36	0.62
MAY	1.37	3.03	2.12	3.13	2.42	0.34	0.0
JUN	1.16	0.0	0.63	1.50	0.76	0.39	0.70
JUL	0.40	1.3	0.62	3.91	2.21	0.38	1.04
AUG	0.0	0.0	1.19	3.49	2.20	0.0	1.41
SEP	1.54	1.42	1.35	2.81	1.60	0.0	0.0
OCT	1.46	0.0	1.22	5.78	3.54	0.0	0.74
NOV	0.0	2.83	0.73	3.84	4.37	0.64	1.19
DEC	0.0	0.0	2.03	0.80	1.01	0.83	2.15
JAN	1.18	0.0	1.79	2.19	0.90	0.79	0.0
FEB	1.54	0.0	0.0	0.66	0.87	0.24	0.82
MAR	1.61	1.12	2.01	0.59	0.77	0.0	0.35
APR	1.15	0.0	0.0	0.54	0.69	0.41	0.93
MAY	0.78	1.10	2.98	0.58	0.73	0.0	0.85
JUN	0.43	0.0	0.0	2.00	2.47	0.0	0.36

APPENDIX C

ACCIDENTS PER HUNDRED PILOTS/AIRCRAFTS
CURVES

(Linear Interpolation Between Data Points)

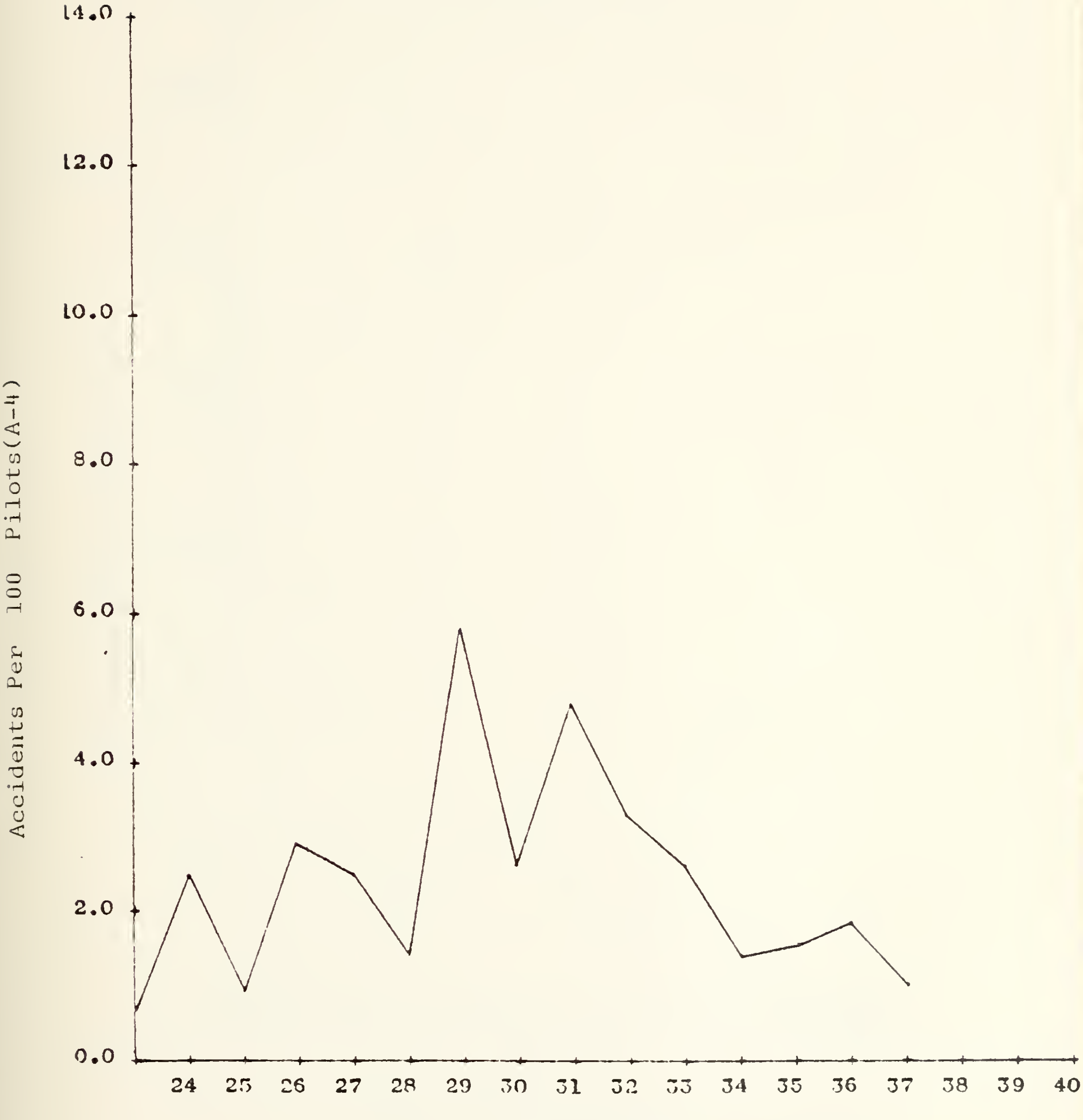

Figure C1: Accidents Per 100 Pilots in each Age Category(A-4)

Figure C2: Accidents Per 100 Pilots
in each DNA Category(A-4)

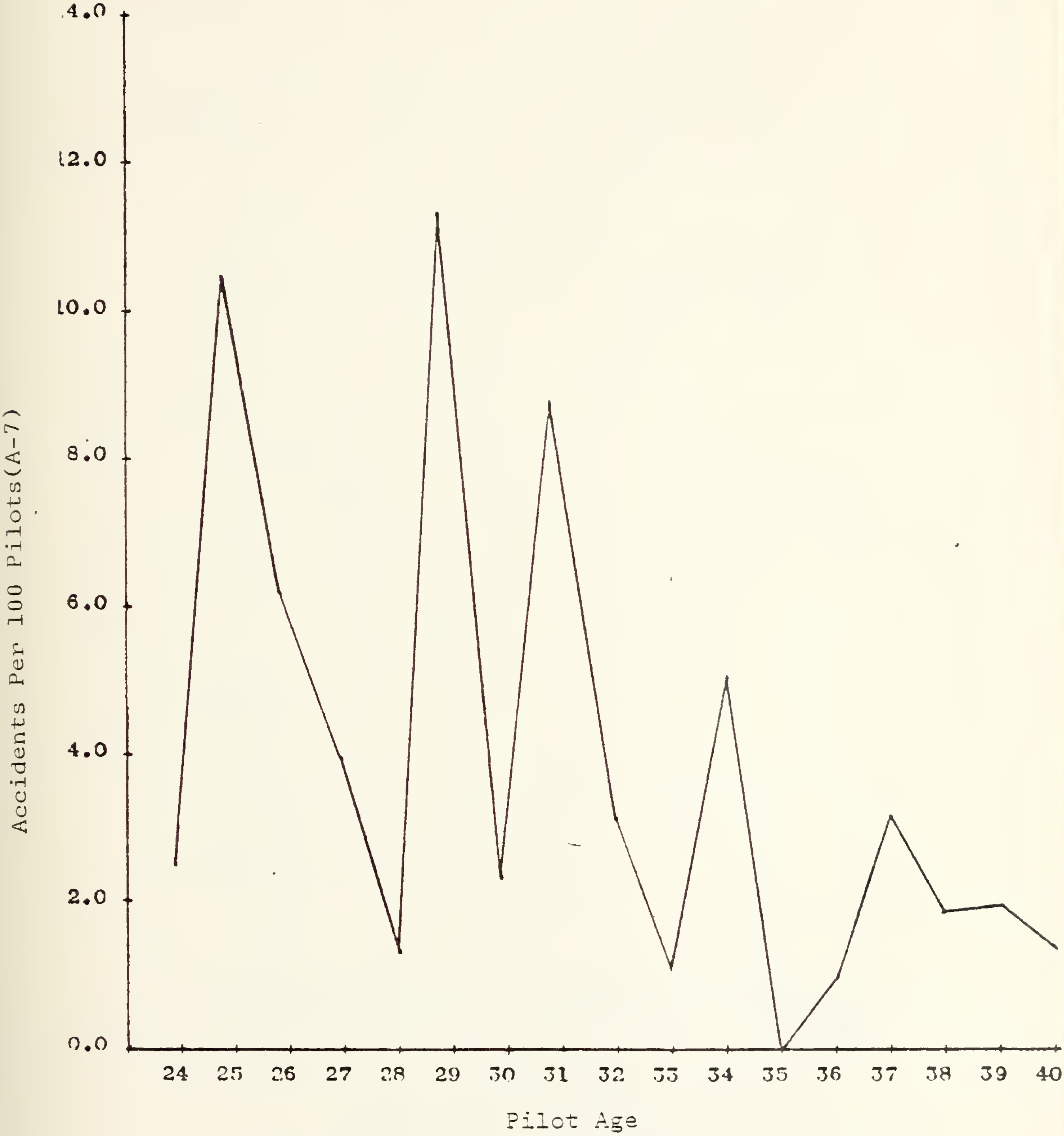

Figure C3: Accidents per 100 Pilots in each Age Category(A-7)

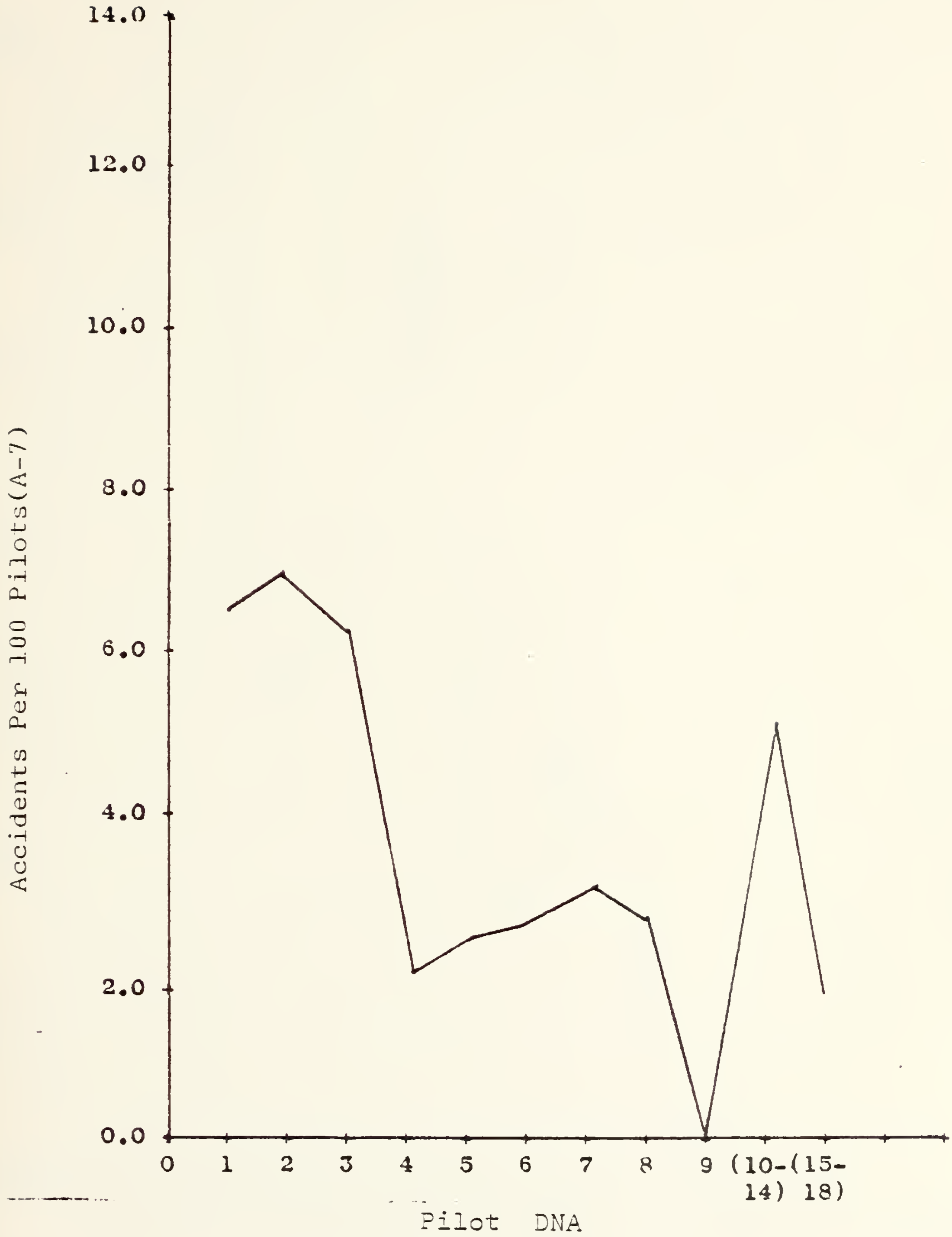

Figure C4: Accidents Per 100 Pilots in each DNA Category(A-7)

Figure C5: Accidents Per 100 Pilots in each Age Category(F-4)

Figure C6: Accidents Per 100 Pilots in each DNA Category(F-4)

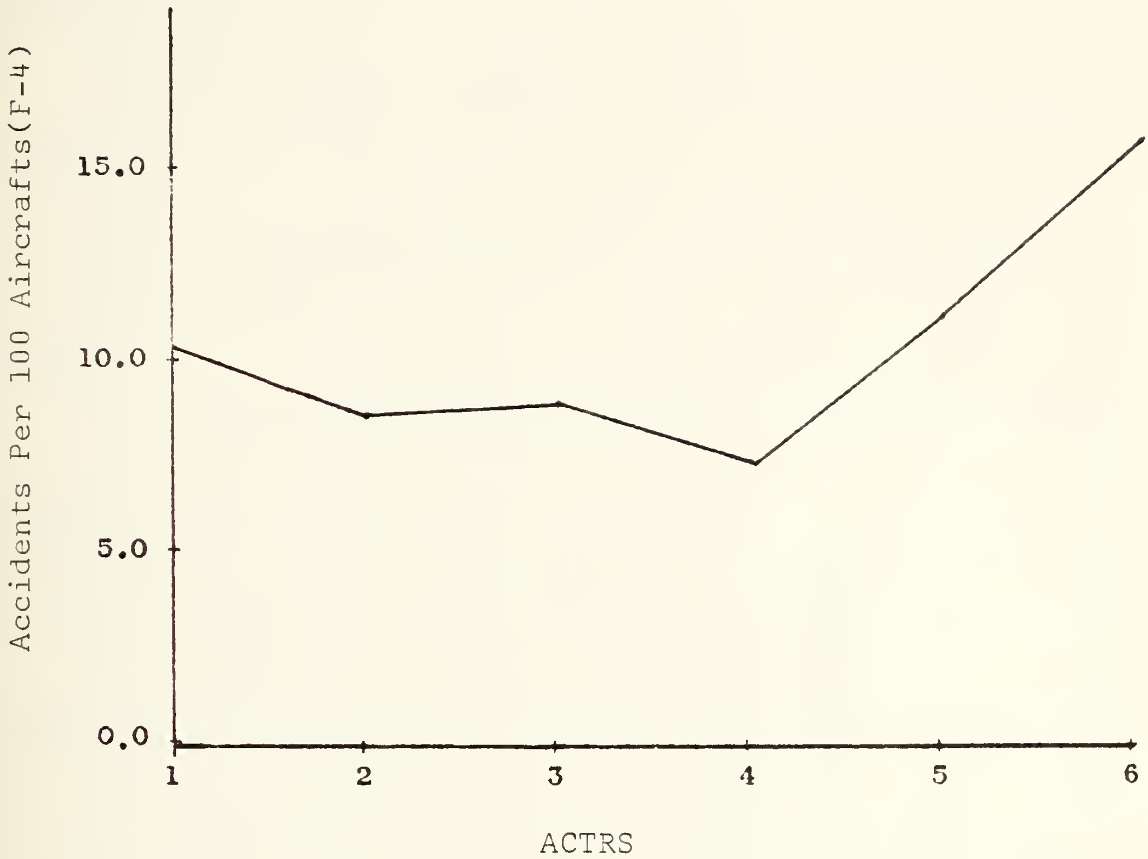

Figure C7: Accidents Per 100 Aircrafts in each ACTRS Category(F-4)

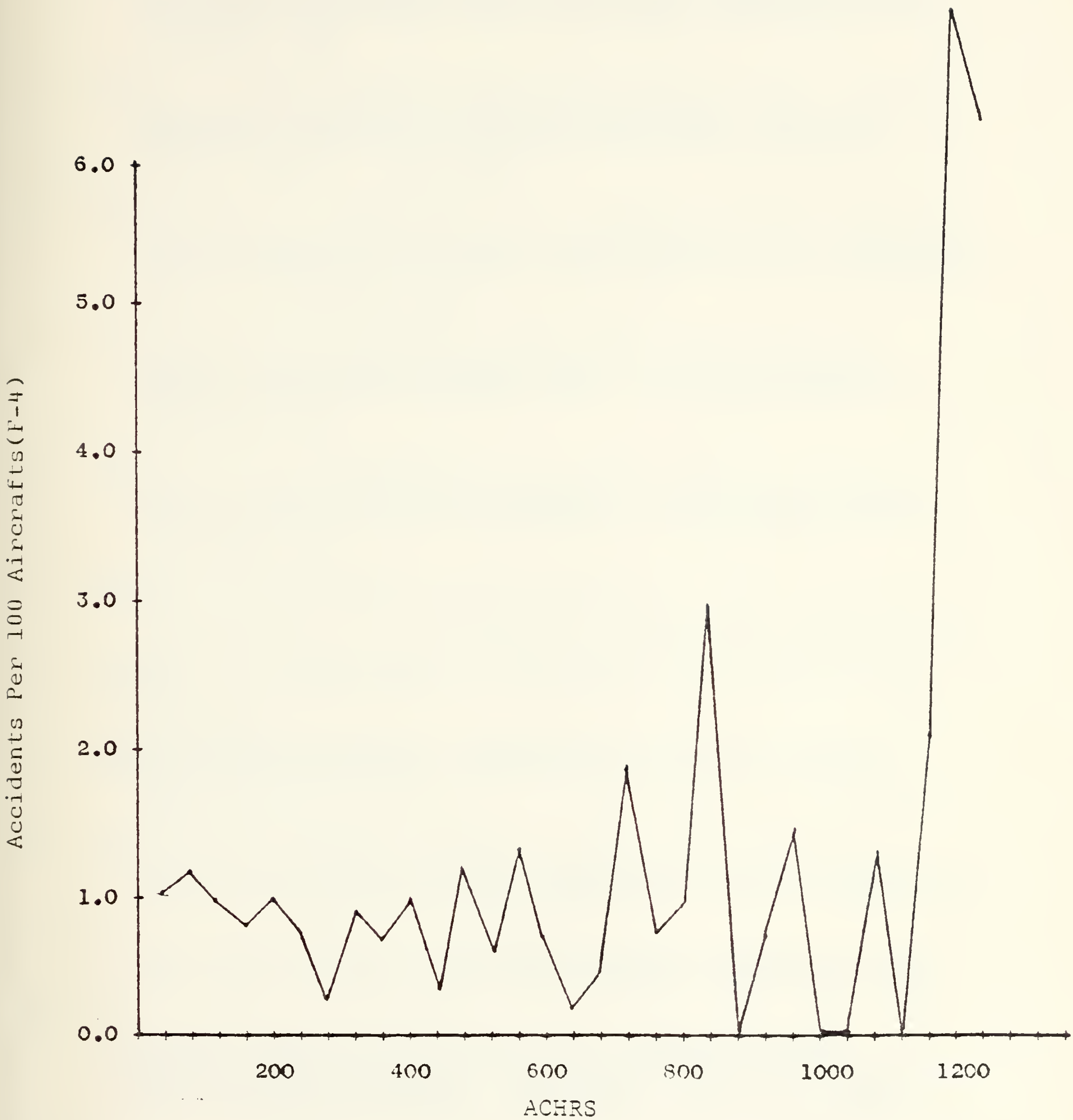

Figure C8: Accidents Per 100 Aircrafts in each ACHRS Category(F-4)

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